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Erica Hanson
Portland State University

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Thinking Through Consciousness

By

Erica Hanson

An undergraduate honors thesis submitted in partial fulfillment of the
requirements for the degree of

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Thesis Adviser

Dr. Josh Fost

Portland State University

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“...human beings have a discursive instrument by which to assert (meaningfully) that the world of human actions is both real and mysterious, that is, is mysteriously real (which is not the same thing as saying that is it a real mystery); that what cannot be explained is in principle capable of being understood; and that, finally, this understanding is nothing other than its representation in the form of a narrative.”

Hayden White

Consciousness is difficult to pin down. Most human beings go about their days with full and more or less uninterrupted consciousness, without contemplating their own (or other peoples') conscious states. To be in the world, and accomplish great acts takes little meta-awareness of consciousness, but in the study of consciousness our inability to think outside of our conscious states creates controversies at the conceptual and methodological levels. As Victor Lamme states (2006), even when we set aside the more difficult (or more poorly defined) questions about conscious experience to focus on finding the neural correlates of consciousness (NCC), we face immense difficulties (Lamme, 2006, p. 494). Experiments designed to find the NCC often involve the manipulation of conscious states through anesthesia, the study of sleep, or brain lesion studies (Lamme, 2006, p. 494). However, even in the case of anesthesia, where we can voluntarily induce a reversible altered state of consciousness there does not seem to be a clear dividing line between consciousness and unconsciousness with any of the processed electroencephalogram (EEG) signals (Güzeldere, 1998, p. 1) such that the conscious and unconscious states are still confirmed behaviorally

(Lamme, 2006, p. 494). This leads to a problem, as it must be decided what “behavioral measures ‘count’ as evidence for the subject having conscious experience (p. 494)” a problem that is not so simple as the ability to speak and respond, as will be more clear in a later discussion of intraoperative awareness. Furthermore, Güven Güzeldere points to the difficulty of defining what “the problem of consciousness” is, within and “across disciplinary boundaries (Güzeldere, p. 7).” The problems that philosophers of consciousness, cognitive scientists and neuroscientists address when they study consciousness are not inevitably going to be identical, but are shaped by disciplinary perspectives, methods and technologies.

Therefore, In this paper I am going to contrast two similar models of consciousness, Giulio Tononi’s Integrated Information Theory and Daniel Dennett’s Multiple Drafts Model, and evaluate them against the mechanisms of several anesthetics (Propofol, ketamine, and the inhalation anesthetics, including xenon), which will be summarized by a review of the literature. I have two goals in mind with this project: first, I have chosen two very similar models¹ in order to demonstrate how small differences- such as Tononi’s engagement with the concept of qualia and Dennett’s deconstruction of it- have large implications for what types of knowledge are possible when these models are applied; second, I am summarizing the literature concerning the study of anesthetics to show both that anesthetics are useful for the elucidation of the neural correlates of consciousness, and that there is a danger of conflating the neural correlates of unconsciousness with a full description of how consciousness arises, or what consciousness is. Moreover, I will argue that because Dennett’s model specifically addresses the importance of

¹ The models of Tononi and Dennett are often paired together when models of consciousness are categorized. In Atkinson et al.’s paper, “Consciousness: mapping the theoretical landscape” they argue that the models of Dennett and Tononi can both be categorized as non-specialized, process oriented theories (Atkinson, 2000, p. 377). These models, they argue, posit that “consciousness depends on specific processes that can take place in any region of the brain (378).”

language in shaping human consciousness, despite the distance between his model and a full neurobiological approach, his model is more useful going forward. It must be emphasized that I am not arguing that Dennett's model is the correct model of consciousness, but that he is thinking about consciousness in the right ways.

1. **Consciousness- what the hell is it?**

Going back to a previously stated problem, how can we define what consciousness is? In 1899, the psychologists George Stout declared "What is consciousness? Properly speaking, definition is impossible. Everybody knows what consciousness is because everybody is conscious (p. 7)." But other scholars have been more willing to offer tentative descriptions that go beyond merely listing a few phenomenal examples. Jean-Pierre Changeux (2006) summarizes the different "levels of consciousness" that appear across -and within, during different stages of development- different species²: a lowest level of minimal consciousness that corresponds to the 25-30 week preterm fetus (and approximately, newborn rats/mice) in which the subject is able to "process tactile and painful stimuli in the sensory cortex" and pain; the second stage, characterized by the "functional use of objects and by proto-declarative pointing" may also include a social factor, as the new born infant has the awareness to differentiate the self and not-self, and construct multiple mental representations; the third stage is characterized by working and episodic memory and basic aspects of language, "self-recognition in the mirror tests" develops in children around age two; finally, full consciousness,

² This is not without controversy- Differentiating human consciousness from animal consciousness has some practical value as there are some quirks to human consciousness that do not seem to appear in other species, but anthropomorphism and other ideologies have suffused these discussions. See Dennett, D. (1995) "Animal Consciousness: what matters and why." *Social Research*, 62(3), 691-710.

encompassing theory of mind and “first person ontology and reportability, reaches full development in humans and develops following 3-5 years in children (Changeux, 2006, p. 2240).”

This last state, full consciousness, is often the default state studied in humans and is the most open to philosophical and psychological debate. For instance, Ned Block distinguishes between ‘access consciousness’ which can be easily defined for humans, and ‘phenomenal consciousness,’ which is not so easy (Güzeldere, 1998, p. 28-29). Access consciousness is the state of represented contents, which can be used for reasoning, the control of action and of speech (p. 28). Phenomenal consciousness on the other hand, contains qualia, the ‘raw feels’ of our experience, the “way it feels to ‘see, hear, smell, taste, and have pains,’” or the “what it is like” to be us (p. 28). Güzeldere states that Block’s definition of p-consciousness suffers from a circuitousness that his definition of a-consciousness does not, and questions whether our inability to provide ourselves with a simple definition is indicative of a conceptual weakness that contributes to “the explanatory gap (p. 29).” For many philosophers and neuroscientists, qualia seem to be a particular sticking point, and the phenomenon of qualia becomes the firm point from which to raise the world.

The question, “what is it like to be a ____” comes from Thomas Nagel’s 1974 paper, “What is it like to be a bat?” in which he argues that if an organism has conscious mental states, there “is something that it is like to *be* that organism (Nagel, 1974, p. 436).” This *what it is like* is the subjective experience of the individual, and as such is not “analyzable in terms of any explanatory systems of functional states, or intentional states, since these could be ascribed to robots or automata that behaved like people though they experienced nothing (p.

436).”Furthermore, it is not only possible that human consciousness is one of those “facts which could not ever be represented or comprehended by human beings, even if the species lasted forever—simply because our structure does not permit us to operate with concepts of the requisite type.” But that it is likely (p. 441). This, he argues, is because human experience is necessarily from one point of view, and one only, inaccessible to scrutiny by another (p. 442). Nagel has argued against the materialist³ explanation of the origin of the mind and consciousness, and as such he is aligned with the non-reductionists in the philosophy of consciousness (NRC) who likewise argue that consciousness is not reducible to physical processes (Nagel, 2012, p. 5).

For thinkers like who disavow materialism, NRC poses little logical conflict. The famous philosophical zombie is meant to demonstrate the weakness of the physicalism in the philosophy of consciousness (PC). The philosophical zombie is a creature that is physically identical to fully conscious human beings in every way but one— the philosophical zombie does not have subjective experience. The question is, is such a being possible? For NRC, it is— after all, the molecular organization and behavior of a subject aren’t what cause consciousness, something else must be present. This thought experiment was used to illustrate some of the difficulties of the reductionist approach; according to Chalmers, our ability to conceive of a philosophical zombie ⁴ *by itself* negates the necessary conditions for PC to be true (LaRock, 2010, p. 234).

³ Nagel is an avowed atheist.

⁴ The argument goes: Zombies are conceivable; whatever is conceivable is possible; therefore zombies are possible.

NRC is harder to reconcile with materialism, and many of those in favor of materialism favor PC. For PC, zombies are simply not possible- if a zombie is physically identical to a fully conscious human being, then that zombie *must* also be conscious. Daniel Dennett has for the most part ⁵argued that zombies cannot exist. Furthermore, he argues that the conceivability of zombies is not sufficient for a refutation of PC. After all, we can imagine lots of things- beings, creatures and objects- that do not, and cannot exist. In a rather tongue in cheek example, he offers the philosophical zimbo: a zombie that “has internal (but unconscious) higher-order informational states that are about its other, lower-order informational states (Dennett, 1991, p. 310).” So, the zimbo is a creature who thinks it is conscious (who appears to have a subjective experience) when it is not. If such a creature is conceivable, it is possible, and we are back at the beginning again, with little resolved. However, if such a creature is not possible, then the argument from conceivability fails, and the philosophical zombie has resolved nothing.

Both of the theories that I am going to discuss situate themselves within materialism, and posit models of consciousness that are supervenient to physics. So, the question is, how do they accomplish this? Giulio Tononi’s Integrated Information Theory (IIT) advances that the amount of consciousness corresponds to the amount of integrated information (II) in the brain, and has developed a theory that seeks to define qualia mathematically. The concepts that he uses are based upon several phenomenological thought experiments, and ultimately seek to answer to main questions: “What are the necessary and sufficient conditions that determine the *quantity* of consciousness generated by a system?” and

⁵ He does argue for an alternative approach to the question: Zombies are possible, and actual, because we are zombies (Dennett, 1991, p. 406). This isn’t a rejection of the possibility of consciousness, as the later elaboration of Dennett’s multiple drafts Model will hopefully make clear.

“what are the necessary and sufficient conditions that determine the quality of consciousness generated by a system (Balduzzi, 2009, p. 1)?” He begins with a thought experiment comparing the reaction of a single photodiode to a series of flashed images to that of a human. The photodiode is a system that contains a sensor and a detector, each of which can be either on (1) or off (0). Thus, the system as a whole can be in four unique states (11, 10, 01, 00) each with a 25% probability of occurring, and this set of possibilities constitutes the potential repertoire of the system. When an image is flashed on the screen that is of sufficient brightness, the diode will react and both the sensor and the detector will assume a certain state, say 11. This actual state determines what the previous possible states of the system must have been (11 or 10)⁶, each with a 50% possibility of occurring, and this forms the actual repertoire of the system. It is here that Shannon’s information theory comes in- the Kullback-Leibler divergence⁷ is a measure of the information *lost* when one probability distribution is used to approximate another, and is applied to the two distributions that occur for the diode. When the potential distribution has high entropy and the actual system has low entropy, the information generated will be high because of the large number of potential states that have been ruled out⁸.

Now, returning to the thought experiment for a moment, when a human is shown an image on the screen the human will be able to response to gross differences in the brightness,

⁶ This is an important point- the mechanism of the system and the state specifies “an *actual* (a *posteriori*) distribution (Tononi, 2008, p. 220).” So, the mechanism of the system determines a great deal about what probability distributions for the system are possible, and since KL divergence, the concept used to determine the amount of information in the system, the mechanism is quite important. IIT doesn’t specify what mechanisms are necessary, only that the systems’ of mechanisms generate a large amount of II.

⁷ The KL divergence for a given probability $p = \{p_i\}$ and a reference distribution $q = \{q_i\}$ is:

$D_{KL}(p \parallel q) = \sum_i p_i \log_2 \frac{p_i}{q_i}$. D_{KL} is non-negative, zero if the distributions are identical and can potentially diverge to infinity.

⁸ Tononi states that when noise dominates the information generated will be low because many possible states could have led to the current one and no alternatives have been eliminated (Tononi, 2008, p. 220).

but also to whether or not the image has blue in it, or is of a triangle or a square, or shows an angry face instead of a happy one. The human in this case is discriminating between many thousands or millions of alternatives, generating a much greater amount of information with each alternative that is eliminated. This alone isn't sufficient to differentiate between a human, and a complex system of two million diodes would generate two million bits of information, an incredible amount. Nonetheless, this two million diode system would still not be conscious, and the key is integration (Tononi, 2008, p. 218-219).

The amount of integrated information generated by a system is calculated in the same way as the total information generated by the system as a whole, using the Kullback-Leibler divergence⁹. The value produced is designated Φ , and corresponds to the quantity of consciousness generated by a system. Tononi makes a number of observations to corroborate the connection between Φ and the quantity of consciousness- he notes that for complexes (small subsets of a system) that form repeated units, the entropy (and therefore Φ) of the system would be low, which may explain why the neuron-dense cerebellum does not significantly contribute to consciousness (p. 221). Additionally, Φ could explain the phenomenal experiences of split-brain patients- when the corpus callosum is cut, there is a reduction in the integrated information, but due to the redundancy between the two hemispheres, the entropy of the system is not increased significantly, and the change in Φ is low (p. 223). Finally, he states

⁹ This calculation takes a slightly different look from before: $\Phi \left(\prod p(^k M_0(mech, \mu_1)) \parallel p(X_0(mech, x_1)) \right) = \sum_i \prod p(^k M_0(mech, \mu_1)) \log_2 \frac{\prod p(^k M_0(mech, \mu_1))}{p(X_0(mech, x_1))}$, for $^k M_0 \in MIP$ and $p(X_0(mech, x_1))$ defines the potential information generated by the system, and $\prod p(^k M_0(mech, \mu_1))$ is the product that defines the total information generated by all of the parts, when the system as a whole is decomposed into the minimum information partition, or MIP. The MIP is the decomposition of the system that leaves the least amount of information unaccounted for (Tononi, 2008, p. 220).

that computer simulations also show that II can be reduced by near-synchronous neural activity, which could explain the absence of consciousness observed during seizures (p. 223).

While the amount of II determines the quantity of consciousness, the generation of qualia takes a different form. For a system of n -binary elements, there are 2^n possible states that the system as a whole can be in and it can be posited that each possible state has an associated dimension in space, designated qualia space (p. 224). For each axis in qualia space (q-space), there is a probability associated with that state. If all of the elements of the system are disconnected, then the system is in a state of maximum entropy and each possible state of the system has an equivalent probability of existing. The total probability of all the states together must sum to one, and so all of the probabilities for all dimensions converge on a point in this q-space. Just as before in the calculation of II , the actual state of a system determines what the *previous* state of a system could be. So, when a connection is formed between at least two elements in the system, the possibility that the system will exist in certain states reduces to zero, while the probabilities of other states increase. When these new probabilities are summed, they converge on a new point in q-space. The point in q-space that corresponds to the maximum entropy can be connected to the points in q-space that correspond to actual states, forming a vector called a q-arrow. The length and direction of the arrow contains information about the connection between elements that determines the system's actual state (p. 227). Each possible connection between elements produces the same effect: new points in q-space, and therefore new q-arrows. Finally, the relationship between connections themselves can be represented by the summing of two arrows in q-space to form a new arrow. When this process has been repeated for all possible combinations of connections between elements in

the system, building logically from an initial connection, the arrows will converge on a single point that corresponds to the actual repertoire of the system (p. 227). Finally, the edges that are formed by the q-arrows and concatenated q-arrows form a shape in q-space, and this shape determines a quale.

Where Tononi seeks to develop a mathematical model of consciousness that can explain qualia, Dennett disregards it altogether. His Multiple Drafts Model of consciousness describes "...All varieties of perception- indeed, all varieties of thought or mental activity- are accomplished in the brain by parallel, multitrack processes of interpretation and elaboration of sensory inputs. Information entering the nervous system is under continuous 'editorial revision' (Dennett, 1991, p. 111)." The purpose of this interpretation and elaboration of sensory data is not the representation of experience in the form of qualia, but behavioral modification, for the actions of the future body. In his chapter "Qualia disqualified" Dennett proposes the metaphor of a kite string: a snarled string, in principle, can be untangled, but at a certain point it may not be worth the effort- you might as well get a new kite string (p. 369). This is an unobtrusive metaphor that belies how deep Dennett's objections to the very idea of qualia go; the problem with qualia isn't simply that it is a concept that has been too steeped in controversy, an idea that cannot be looked at with fresh eyes and a fresh framework. The problems with qualia are the assumptions that are built into the belief that there can be such a thing as qualia at all. For the belief in qualia is the belief in a separate, inaccessible, unverifiable truth in experience that both exists outside of the materialist (and evolution-based) framework, and assumes that the 'intrinsic' properties of experience are outside the influence of the human knower, his neuroanatomy and linguistic and social cultures. This first point- that thorough evolutionary

explanations of experience are enough to justify and demystify *why* an experience *feels* the way it does to us- is fairly simple to demonstrate.

The intuitive nature of the discussion about qualia often forecloses the possibility of arguments that don't satisfy us on this gut level. As Dennett states, "The idea that there are such qualia just distracts us from all possible paths of explanation, capturing our attention the way a wagging finger in front of a baby's eyes can capture its attention, getting us to stare numbly at the 'intrinsic object' instead of casting about for a description of the underlying mechanisms and an explanation (ultimately an evolutionary explanation) of why the mechanisms do what they do (p. 409)." Implicit in the statement that there is something that it is like to be us is the recognition that there doesn't have to be. But it is dangerously easy to elide the *reason* that there is a something that it is like, to conflate the mysterious reality with a real mystery when the reason for our rich and enjoyable experiences is as simple as getting us to do stuff. Dennett states, "it is not the point of sensory systems that they should detect 'basic' or 'natural' properties of the environment, but just that they should serve our 'narcissistic' purposes in staying alive; nature doesn't build epistemic engines (p. 382)."

Part of the reason that we are so able to get stuck in the seductive tangle of our intuitive explanations is that we are not skeptical of the reality of our internal states. He states, "I suspect that when we claim to be just using our powers of inner observation, we are always actually engaging in a sort of impromptu theorizing (p. 67)." When we experience paradoxical phenomena, we can describe the phenomena accurately and productively, but we usually cannot correctly (or even definitively) describe why such and such a phenomena occurred. As an example, Dennett mentions a discussion he had with the philosopher Ned Block, who was a

participant in a study observing 'Laterality'. In tests of laterality, a subject is instructed to look ahead at a point, while words and non-words are briefly flashed in the right or left margins of the subjects' vision. If the stimulus is a word, then the subject is instructed to press a button. Most subjects respond more slowly to words flashed on the left side, because most people are strongly lateralized for language in the left hemisphere, and visual information entering from the left of the visual field is perceived by the right hemisphere. Block noted that the words from the left visual field seemed blurrier. Dennett asks "whether he thought the words were harder to identify because they seemed blurry, or seemed blurry because they were harder to identify. He admitted that he could have no way of distinguishing these 'opposite' causal accounts (p. 133n)."

Another example of this problem is that of Koler's color phi phenomenon. This phenomenon occurs when two spots that are only separated by a very small distance are flashed very quickly, first one, then the other, creating the illusion that one spot simply moved (p. 114). This phenomenon persists even when the two spots are of different colors (first blue, then yellow), creating the illusion that the spot changed color mid movement, which would seem to occur before the second spot had been perceived. Two competing explanations for what is occurring here have been forwarded: first, there is the Orwellian account which supposes that first the blue spot was perceived, then the yellow spot was perceived, and then in our memory we construct the illusion of a blue spot moving, and changing to a yellow spot at the same time; second, there is a Stalinist account that supposes that the error occurred at the point of perception, that you "hallucinated" the moving, color changing spot as if there was a delay in the representation of your visual data that was altered before you "saw" it (p. 117). In

one account, the illusion happens at the point of memory, and in the other, at the point of perception. Dennett argues that not only is it impossible to judge for ourselves which explanation fits our experience, but that from the third person perspective, there is no way to accumulate data that would support one account without simultaneously validating the other (p. 124). This implies that despite our strong intuition otherwise, there is no “privileged finish line so the temporal order of discriminations cannot be what fixes the subjective order in experience (p. 119).” Any attempt to determine such a line is arbitrary on our part, and must be treated as such.

Instead of a naïve form of phenomenology, which would assume that subjects’ reports about their experiences contained the truth of their experiences, Dennett proposes a heterophenomenology, characterized by “a constructive and sympathetic neutrality, in the hopes of compiling a definitive description of the world according to its subjects (p. 83).” The task of a heterophenomenologist is analogous to the task of a reader interpreting a fictional work. In the same way that we can interpret a fictional world we know is fake we can interpret the reported experiences of a subject without assuming that these experiences are necessarily ‘true’.

Returning for a moment to Koler’s color phi phenomenon, the assumption that we can use subjects reported experiences as raw data, and not as a text that must be cautiously interpreted leads to an ‘intuitive’ assumption that there is a single, canonical version of our experience, a true ‘representation’ of our sensory experiences that is altered somehow when it is either misremembered or altered and re-presented. This is the problem of the Cartesian theater, a place in the brain where “it all comes together, “and where all experiences

interpreted from sensory discriminations are bound (p. 107). According to Dennett, “The idea of a special center in the brain is the most tenacious bad idea bedeviling our attempts to think about consciousness (p. 108).” This is because the metaphor of the Cartesian theater encourages us to believe in a “unity of consciousness,” and think about our bodies, and the selves that they are, as the firm boundary between ‘in here’ and ‘out there (p. 108).” Although it a sneaky kind of dualism, in the way that it encourages us to think of consciousness as possessing firm and finite boundaries that can be measured and traced, as if consciousness were an additional substance separate from the brain states that correlate with it, it also implies an impossible isolation between the experiencer, the “knower” and their environment. The omnipresent critic in *Consciousness Explained* makes the statement at the end of the chapter on qualia:

Consider [says Otto] the way the pink ring seems to me right *now*, at his very moment, in isolation from all my dispositions, past associations and future activities. *That*, the purified, isolated *way it is with* me in regards to color at this moment- that is my pink quale (p. 386).

But the obvious problem with this passage is the utter impossibility- and imbecility- of separating the person experiencing the quale from their past experiences, memories and preferences. It is logically impossible. For Dennett, there is no splicing the ‘knower’- the self- from the myriad narratives that compose experience. He quotes a satirical passage in the novel *Nice Work* by David Lodge (1988), which exaggerates but exemplifies Dennett’s view of the self:

...there is no such thing as the ‘Self’ on which capitalism and the classic novel are founded-that is to say, a finite, unique soul or essence that constitutes a person’s

identity; there is only a subject position in an infinite web of discourses- the discourses of power, sex, family, science, religion, poetry, etc. And by the same token, there is no such thing as an author, that is to say, one who originated a work of fiction *ab nihilo*... in the famous words of Jacques Derrida... 'il n'y a pas de hors-texte', there is nothing outside the text. There are no origins, there is only a production, and we produce our 'selves' in language... (Dennett, 1991, p. 411).

So, this then is the other heart of the problem with qualia- it encourages us to think of our experiences and our 'selves' as separate and separable from our evolutionary, cultural and linguistic baggage. For Dennett, the self is not " any old mathematical point, but an abstraction defined by the myriads of attributions and interpretations (including self-attribution and self-interpretation) that have composed the biography of the living body whose Center of Narrative Gravity it is (p. 427)." Dennett shows how closely tied this view of the self is with language, and with our narrative capacity and inclinations, and, moreover, how such a view of consciousness is compatible with a materialist view of the mind, and an evolutionary approach to the history of consciousness. He accomplishes this by means of metaphors from computer science. Altogether, Dennett's view of human consciousness is "the operations of a 'virtual machine,' a sort of evolved (and evolving) computer program that shapes the activities of the brain. There is no Cartesian Theater; there are just Multiple Drafts composed by processes of content fixation playing various semi-independent roles in the brain's larger economy of controlling a human body's journey through life (p. 431)."

At this point it should be clear that there are deep swaths of similarity between these two conceptualizations of consciousness, and equally important, and no less grave, differences.

The impact of these differences becomes the most clear when juxtaposed with the phenomenon of intraoperative awareness. In the following sections, I will summarize some of the facts of anesthetic action and intraoperative awareness, and take a careful look at how these models situate themselves to handle the phenomena like intraoperative awareness.

2. Anesthetics and their mechanism of action

At the current time, there is no consensus about the mechanism of anesthetic action, as many anesthetics act on multiple receptor types, with no single receptor type agonized or antagonized by all drugs. There is a class of lipid-soluble anesthetics that do not cause loss of consciousness (LOC) or immobility, but do affect learning (John, 2005, p. 448), and for a time it was thought that lipid-solubility was the important factor in a general anesthetic mechanism. This view has since yielded to the assumption that most anesthetics that cause LOC act on membrane-bound proteins, by “structural or dynamic consequences such as conformational changes in the target protein, stabilization or attenuation of subunits association, equilibrium shift, or competition with endogenous ligands (Ishizawa, 2006, p. 187).” Furthermore, the individual effects of anesthetics- primarily analgesia, amnesia, immobility and hypnosis- are caused by actions at different brain regions (John, 2005, p. 448). For the most part, it is believed that the anesthetics that cause analgesia are working at the level of the spinal cord, while cortical structures are involved in the suppression of arousal and memory (p. 448). Different anesthetic effects appear at different concentrations of anesthetic drug; memory is inhibited at lower drug concentrations than the suppression of movement and breathing (Ishizawa, 2006, p. 190). There are a number of different levels of organization by which anesthetic action, from the molecular and sub-molecular up through the behavioral, and for the purposes of my review

I am just going to first briefly discuss a few anesthetic agents themselves, before introducing one of the most important phenomena affecting both consciousness studies and anesthetic research: Intraoperative awareness.

There is no unifying structural feature that explains why a certain molecule can act as an anesthetic- the relatively polar halogenated ethers, as well as the non-polar noble gas xenon both cause sedation. This insight also suggests that there is no “specific receptor that mediates general anesthesia (Ishizawa, 2006, p. 190). Nonetheless, most anesthetics can be separated according to whether or not they agonize type A GABA¹⁰ receptors (propofol, the halogenated ethers¹¹) or antagonize the NMDA¹² receptor (ketamine, xenon, nitrous oxide (NO)).

Propofol and the halogenated ethers all act as GABA type A receptor agonists, with variations in anesthetic effect and side effects due to the additional and varied effect on other receptor types, the effective dosage required, and general binding energetics (Ishizawa, 2006, p. 190). There are many subunits of the GABA_A receptor, but gamma2 subunit appears to be the locus of action for propofol-induced enhancement of GABA potency (Zecharia, 2010, p.13072). Neil Harrison (2002) found that propofol, by stimulating the inhibitory effects of GABA_A receptors (GABA_AR), specifically targets the hypothalamic ventrolateral preoptic

¹⁰ Gamma-amino-butyric acid. Mature GABA receptors are a type of ion channel that is activated by GABA, and allows the passage of chloride ions into the cell. Action potentials (the mode of neurotransmission) are dependent upon the local accumulation of positive charge inside the neuron, an increase in the concentration of negatively charged ions delays the accumulation of positive charge, inhibiting or preventing an action potential. For this reason, GABA receptors are common inhibitory receptors in the Central Nervous System (CNS) (Purves 133).

¹¹ Most inhalation anesthetics, besides xenon and NO are halogenated ethers. These include desflurane, sevoflurane and isoflurane which will be talked about here.

¹² N-Methyl-D-aspartate. NMDA receptors are a subtype of glutamate receptors, the main excitatory receptor in the brain. NMDA receptors are ionotropic, and are non-selective, voltage-gated channels that allow passage of calcium and sodium ions into the cell, and potassium ions out (Purves 129-130). These channels bind magnesium ions when the neuron is hyperpolarized, which blocks the passage of other ions. When the neuron is depolarized (as happens during an action potential) the magnesium ion is forced out and the passage of the other ions can recommence (Purves, 2008, p. 130). NMDA receptors are involved with plasticity but have been implicated in excitotoxicity following acute brain injury (p. 129).

nucleus (VLPO) and the tuberomamillary nucleus (TMN¹³), two brain regions that are both involved in the control of the sleep/wake cycle (p. 928). As Regis Parmentier et al. (2008) state, “the firing of the TMN is state-dependent, active during waking, silent during sleep (p. 4471).” However, Zecharia et al. (2012) investigated the connection between the hypnosis effect of propofol and potentiation of GABA_AR in the TMN, and found that despite increased excitability in histaminergic neurons missing GABA_AR, at the behavioral level, mice bred to lack GABA_AR had unaffected righting reflexes¹⁴ after injection with propofol (p. 13062). However, Weiser and McCarren (2013) have suggested that the role of the TMN be revisited, as the loss of righting reflex “characterizes the emergence from, but not the induction of, propofol-induced hypnosis (p. 1296).” Furthermore, Yanovksy et al. (2011) demonstrated that “sleep and anesthesia depend on different GABA_AR types” with β 1-containing GABA_AR correlated with sleep, and β 3-containing GABA_AR sensitive to propofol (p. 187). This has been corroborated by separate EEG studies that demonstrate differences sleep and anesthesia (Leslie, 2010, p. 84). Other studies have identified the EEG signature of anesthetic states. Purdon et al. (2013) used the response to either verbal stimulus¹⁵ in human subjects to observe the changes in EEG pattern that correlate with the loss of consciousness due to propofol anesthesia. They found that near the point of LOC there was “an increase in low-frequency EEG power (<1 Hz), the loss of spatially coherent occipital alpha oscillations (8-12 Hz), and the appearance of spatially coherent frontal

¹³ The TMN, a part of the posterior hypothalamus, is the locus from where all histaminergic projections originate. Besides the sleep-wake cycle, the TMN affects “energy and endocrine homeostasis, synaptic plasticity and learning (Haas, 2003, p. 121).” Classic antihistamines cause sedation.

¹⁴ The righting reflex is used to determine hypnosis in mice.

¹⁵ In addition to a verbal stimulus, they used a less salient click stimulus, and found that responses to the click stimulus were lost more quickly during the onset of hypnosis, and delayed during the onset of wakefulness (Purdon, 2013, p. 5).

alpha oscillations (p. 1).” Also, they suggest that anteriorization begins before LOC, in line with the previous finding that anteriorization correlated with LOC (p. 6).

Alkire et al. (2001) found that cerebral metabolism differed significantly for different brain regions depending upon whether propofol or isoflurane was administered, despite the fact that both drugs are GABA_AR agonists (p. 620). It has been shown that propofol does not produce analgesia, and so the co-administration of other analgesics¹⁶ is usually necessary. Alkire et al. found that propofol induced metabolic changes were poorly correlated with opioid binding sites, which could explain this effect (p. 622). They also found that propofol caused a much greater metabolic increase in the basal ganglia, thalamus and midbrain, but was “associated with lower relative cortical metabolic rates (p. 620)”. Kungys et al. (2009) have investigated the localized action of propofol in the Ventral Horn¹⁷ of the spinal cord, demonstrating that this is the site of action for propofol’s immobilizing effects (p. 1531). This same study showed that the immobilizing effect of isoflurane also occurs in the spinal cord, but unlike propofol the effect was localized in the dorsal horn (p. 1534). As noted earlier, the β 3-containing GABA_AR is sensitive to propofol, but Rau et al. (2011) have shown that these receptors are not the target for immobility by inhaled anesthetics like isoflurane, but are the site of action for the induction of hypnosis and amnesia (p. 503). They state further, “our results also suggest that GABA_A-Rs containing the β 3 subunit are important for hippocampal-dependent types of memory such as declarative memory (p. 503). In line with these findings, Bains et al. (2009) have shown that intravenous and volatile anesthetics are correlated with

¹⁶ Usually, opioids such as fentanyl or morphine are given with propofol, although other maintenance anesthetics (such as xenon) themselves have analgesic properties.

¹⁷ As they note, “Neurons in this spinal cord area include central pattern generators and motoneurons (Kungys, 2009, p. 1534). Central pattern generator neurons control rhythmic functions like breathing or walking.

different levels of intracranial pressure, due to the unique mechanisms by which they depolarize the mitochondrial membrane in neurons, a sign of mitochondrial dysfunction that has been implicated in cell death (p. 1354-1357).¹⁸ Jia et al. (2007) have investigated the modulation of extrasynaptic GABA_ARs by isoflurane in the thalamus (p. 1127). The thalamo-corticothalamic loop has been previously investigated for its role in the emergence of consciousness, and as a target for general anesthetics (Koch p. 40, Jia, 2007, p. 1127). The study by Jia et al. had a number of conclusions, but most importantly they showed that isoflurane “induced sustained currents in thalamic relay neurons and that this was completely dependent on the presence of extrasynaptic GABA_A-Rs (p. 1132). However, one of the most interesting effects of isoflurane is the excitement phase that occurs during the ramp-up to the clinical dose (Becker, 2012, p. 1). In their study, they show that at very low doses, isoflurane simultaneously decreases neuronal network excitability in the neocortical layer 5, and increases neuronal network excitability in the hippocampus (p. 5). This, they state, would explain the increased behavioral excitation that happens concurrently with the LOC and the loss of the ability to execute targeted actions (p. 5).

Where GABA_AR agonists work by inhibitory mechanisms, other anesthetics such as xenon exhibit little to no action on GABA_A receptors at all and instead antagonize excitatory glutaminergic NMDA receptors (Wilhelm, 2002, p. 1485). Unlike propofol and the halogenated ethers, xenon is a small, monatomic, inert gas. However, as Preckel et al. (2006) have noted,

¹⁸ For the most part, this is important for patients with high-intracranial pressures, where the risk of ischemia is high. However, the mitochondrial electron transport chain buffers the intracellular Calcium ion concentration, which is a signal substance with wide-reaching effects (Bains, 2009, p. 1358). Thrane et al.(2012) have also shown that general anesthesia disrupts astrocyte calcium signaling (p. 18974). As this type of signaling has been implicated in a number of brain functions, they suggest that the sedative effect of general anesthetic may occur as a result of affected astrocytes as well (p. 18974).

“xenon has a low ionization potential, allowing its electron shell to be polarized by surrounding molecules, thereby inducing a dipole that enables biologic interactions, including binding to proteins (p. 187).” There is evidence that the main anesthetic actions of xenon are due to its role as an NMDA receptor antagonist, but xenon also inhibits nACh receptors, the two-pore-domain potassium channel TREK-1¹⁹, as well as altering calcium signaling by modulating the plasma membrane calcium adenosine triphosphatase (PMCA) protein, which maintains low intracellular concentrations of calcium ions (Preckel, 2006, p. 187-189). For instance, Hasender et al. (2009) found that both NMDA and AMPA receptors were implicated in the hypnotic effect of xenon, exhibiting depression in the prefrontal cortex (p. 1305). However, Preckel et al. (2006) note that “the relevance of xenon’s effects on the cholinergic system to the mechanisms of anesthesia, amnesia, analgesia, and organoprotection are unknown (p. 189).” Much like isoflurane, xenon’s analgesic effect was found to be due to inhibition in the dorsal horn of the spinal cord, independent of opioidergic or adrenergic receptors (p. 189). Hasender et al. (2009) also found depression of NMDA and AMPA receptors in the substantia gelatinosa of the dorsal spinal cord (p. 1305). Meanwhile, xenon also exhibits a neuroprotective capacity. Sanders et al. (2005) state, “almost all NMDA antagonists tested so far exhibit psychomimetic behavioral changes; pyramidal neuronal damage in the posterior cingulate and retrosplenial cortices” while xenon can “ameliorate the neurotoxic effects (p. 126).”

Like xenon, ketamine is also an NMDA receptor antagonist, but is classed as a dissociative anesthetic, that additionally shows different effects for each optical isomer

¹⁹ As Sanders et al. (2005) note, “Activation of TREK channels leads to neuronal hyperpolarization which reduces cellular excitability; in addition, this effect is likely enhance [*sic*] NMDA receptor blockade due to the voltage-gated kinetics of this channel (p. 117).”

(Szekely, 1999, p. 1017). They report that the two optical isomers have differing affinities with NMDA receptors, and that “In clinical and experimental studies, the superiority of S(+)-ketamine has been described with regard to anesthetic potency, the extent of analgesia, and perioperative effects and side effects, especially psychological dysfunction (Szekely, 1999, p. 1023).” Nonetheless, in most cases ketamine is administered as a racemate.

As previously mentioned, ketamine is an NMDA receptor antagonist, and this accounts for much of the hypnotic effect, as well as neurotoxicity (Hirota, 1996, p. 441). Additionally, Hirota notes that “ketamine anesthesia is antagonized by anticholinesterase agents” which causes “postanaesthetic delirium, bronchodilation and sympathomimetic action (p. 442).” Sorce et al. (2010) also report schizophrenia-like symptoms in patients who have received subanesthetic doses of ketamine (p. 11317). This has been attributed to excessive glutamate release, causing “activation of the prefrontal cortex and the limbic structures” after “acute ketamine injections (p. 11317).” As a consequence of this, there is a down-regulation of NMDA receptor 2A expression, which are “mainly expressed in cortex and hippocampus, in which they regulate numerous neuronal functions and, in particular, synaptic plasticity (p. 11324).” Further, a “lower density of NMDA receptor subunit 2A, but not 2B [sic] has been described in postmortem brain samples of patients with schizophrenia (p. 11324).” Likewise, the release of glutamate is thought to underlie the antidepressant action of ketamine (Sorce, 2010, p.11324, Kavalali, 2012, p. 1150). Kavalali et al. report that a single, sub-psychotomimetic ²⁰dose of ketamine can cause an antidepressant effect in patients suffering from major depression immediately, but that this effect also lasts for 1-2 weeks after (p. 1150). Finally, in addition to

²⁰ A psychotomimetic drug is one that induces the symptoms of psychosis.

these psychotic effects, the antagonism of NMDA receptors has been implicated in the analgesic effect of ketamine, which at high enough doses can even perform as a local anesthetic (Baumeister, 1991, p. 351, Hirota, 1996, p. 441).

3. Analysis of the two models- conclusions and criticisms

It should be clear from the previous discussion that the mechanism of anesthesia is complex, and not fully understood. Despite some competing reports, it is still suspected that neural pathways involved in the induction of sleep are also affected during the induction of hypnosis, although it appears that there are several roads to get there. To complicate things further, the proper anesthetic dose is heavily dependent upon individual factors such as weight, previous exposure to anesthetic agents and analogous agents²¹, gender, and age (Ghoneim, 2010, p. 94-96). Thus, it should be no surprise that intraoperative awareness affects approximately 0.1-0.2% ²²of patients a year. The spectrum of patient experiences includes awareness with explicit recall (AWR), awareness without explicit recall (AWO), dreaming during anesthesia with content that may or not contain details from the surgery, and severe postoperative stress and trauma. Understanding the mechanisms and risk factors of intraoperative awareness is important in its own right, but the complexity and variety of phenomena specifically has relevance for the study of consciousness, as anesthetic depth monitoring can be correlated with the changes in EEG power for specific brain regions (as shown by Purdon et al.), and implicit versus explicit learning can be explored with patients under anesthesia (and has been for different age groups) (Davidson, 2010, p. 181-183).

²¹ It was recently shown that low-level, occupational exposure to anesthetic waste gases and vapors increases sensitization for these agents (Gold, 2006, p. 15-16). At the same time, Alexander et al. (2000) showed that suicide and substance abuse pose significant occupational risks for anesthesiologists (p. 922).

²² While this seems like a very small percentage, it amounts to between 20,000 and 40,000 people each year (Palanca 151).

It is relevant to explore how these two models of consciousness navigate these phenomena. Tononi has situated IIT squarely in the field of anesthetic research, as a result of his frequent collaboration with researchers in anesthesia and the provisional acceptance of his theory among researchers. Indeed, much of the evidence concerning the mechanisms of anesthesia line up with his theory well. His 2008 paper with Michael Alkire and Anthony Hudetz offers a generalized, unified theory of anesthetics in the form of IIT. They note that anesthetics usually function by hyperpolarizing neuronal membranes, thus altering the ability of neurons to fire together (p. 1). They further report that “Anesthetic-induced unconsciousness is usually associated with deactivation of mesial parietal cortex, posterior cingulate cortex and precuneus (p. 4).” These portions of the brain, they state, are “strategically located at the main hub of the brain’s connectional core” suggesting that these areas “are the most likely the final common target for anesthetic-induced unconsciousness (p. 4).” Though, they suggest that the loss of integration in these areas, and not deactivation, would be theoretically sufficient to induce unconsciousness (Alkire, 2008, p.4). Anesthetics instead may “disrupt cortical integration by acting on structures that facilitate long-range cortico-cortical interactions, such as the posterior cortical connection hub, certain thalamic nuclei” or “disrupt synchronization among distant areas by slowing neural responses (p. 4).” As stated earlier, Purdon et al. (2013) have shown that LOC was correlated with the loss of spatially coherent occipital alpha oscillations, and Alkire et al. (2008) report a similar finding: EEG coherence is reduced in the gamma range “between right and left frontal cortices and between frontal and occipital regions (Alkire, 2008, p. 4).” For Tononi’s theory, this fragmentation into multiple isolated networks represents a measurable decrease in Φ , and therefore consciousness. It follows naturally from this point that

the dissociative anesthetic ketamine, which causes down-regulation of excitatory NMDA receptors, and thus a decrease in excitatory pathways in the cortex and hippocampus, would also imply a loss of global integration. Sorce et al. (2010) note that this loss of receptor expression also appears in those with schizophrenia, which Tononi has linked to conscious integration (Tononi, 2000, p. 391). In that study, he (along with Gerald Edelman) posits that schizophrenia is a kind of defect in conscious integration (p. 391). Much like anesthesia, “several factors can affect the rapid integration of the activity of distributed thalamocortical regions and the resulting behavioral performance (p. 391).” Nonetheless, Despite the promise of IIT, Alkire et al. observe that “Other frameworks for consciousness, emphasizing access to a global workspace, or the formation of large coalitions of neurons, are also consistent with many of the findings described here (Alkire, 2008, p.7).”

Tononi’s work is also driven by the desire to develop a consciousness meter, as stated in a 2010 interview with Carl Zimmer of the New York Times. Using IIT, consciousness would be quantifiable in the same way as blood pressure or body temperature (Zimmer, 2010, p. 1). In his paper with Michael Alkire, it is suggested “empirical measures could be devised to evaluate integrated information on the basis of EEG data, resting functional connectivity, or TMS-evoked responses (Alkire, 2008, p. 6).” Tononi already has a patent pending the use of TMS-EEG during anesthesia (p. 8). Still, the question remains, how (or would) this work?

There are several good reasons to be skeptical of this project. As previously mentioned, his theory is based in the field of information theory, and calculates the Information contained within a comparison of complex probability distributions. It is fairly easy to imagine how this relates to complex neuronal networks, which can be represented by units with binary states.

However, much of the verification of this theory has been performed by designed models of neuronal networks and brain states to show that the calculated value of Φ appears to correlate well with the level of consciousness. The question is how would this actually work when the measure value of Φ belongs to an individual, and not a computer model? As we have seen with the mechanisms of anesthetics, the response from individual patients to a drug can vary dramatically. Furthermore, as Christof Koch (2009) notes in an article published in *Scientific American Mind*, a rigorous mathematical treatment of consciousness (based upon the connectivity of our 100 billion neurons) is hampered by the fact that Φ for such a system is currently impossible to compute; in fact, “To accurately evaluate Φ for the roundworm is utterly unfeasible, even using all of Google’s more than 100,000 computers (Koch, 2009, p. 19).” Of course, future computing technology may solve that problem, but at the current time this severely limits the systematic applicability of Φ in cases of intraoperative awareness. Supposing EEG measurements were used, as suggested by Alkire, there may be other issues for validating IIT as a theory of consciousness.

Currently, EEG measurements such as the Bispectral Index²³ employ “proprietary algorithms to analyze the EEG and produce a dimensionless representation of anesthetic depth (Garcia, 2010, p. 141).” However, EEG is a fairly gross measurement, much larger than the measurement of single, or even a few groupings of neurons. It isn’t obvious how it would be used as a measure of the information contained in active neural connections. Furthermore, other refinements of EEG have been made without the conceptual backing of a coherent theory of consciousness

²³ It should also be noted that the reliability of BIS is heavily dependent upon the anesthetic used: BIS was developed concurrent with the use of GABA agonists such as propofol, and can be unreliable with NMDA antagonists (Garcia, 2010, p. 141).

(p.139-143²⁴). If IIT's contribution of the EEG measurement of anesthetic depth (as level of consciousness) is no greater than other refinements of EEG and BIS, it doesn't justify the use of Φ outside of a research setting, severely limiting the value of the theory in this context.

Aside from practical concerns, there are other reasons to be skeptical of Tononi's idea for a consciousness meter. From an ethical standpoint, what would be the consequences of a linear, numerical system for measuring consciousness as Φ ? As previously shown, anesthetics have very complicated and varied mechanisms on the molecular and cellular level, tools to measure anesthetic depth are very dependent upon the anesthetic used (e.g., BIS), behavioral signals are not perfectly reliable, and anesthetic depth depends upon individual factors like weight and gender. Returning for a moment to the case of intraoperative awareness²⁵, what kind of value for Φ would a consciousness meter have? In an ideal case Φ would correlate strongly with the level of consciousness, but Alkire et al. acknowledge that IIT necessarily

²⁴ See: A-Line ARX Index (AAI) (Garcia,2010, P. 141).

²⁵ For philosophers of consciousness, awareness with (and without) explicit recall can pose an interesting opportunity to explore some philosophical issues. Eric LaRock has suggested that cases of intraoperative awareness (broadly defined) represents a real life example of an inverse philosophical zombie, a form of the traditional philosophical zombie scenario in which the creature has all of the outward behavioral and measurable signs of unconsciousness, but is in fact conscious (LaRock, 2010, p. 234). Much like the original philosophical zombie, this version is intended as a proof against functionalism, this time in favor of property dualism. LaRock defines property dualism as: "A view that says that conscious mental properties are cause by, but not reducible to, physical properties. Property dualists are not committed to a dualism of substances, but only to a dualism of properties. Among the set of physical substances that exist in this world, there is a subset whose members have evolved suitably complex physical systems (e.g., brains), and these systems have, in addition to physical, functional, and behavioral properties, irreducible conscious mental properties (p. 249)." This is an interesting idea, but has some serious flaws. First, it seems easy (given the current state of our understanding of how anesthetics work and the current ambiguity concerning how to measure the depth of consciousness) to suggest that a patient under anesthesia who experiences intraoperative awareness *is* a real life example of an inverse philosophical zombie. However, this may just be a case of the "mistaking the lack of imagination for an insight into necessity" that Dennett (1991) has described as the "Philosopher's Syndrome (p. 401)." For example, LaRock (2010) proposes that "In the case of inverse zombies, some type of consciousness detector could be used to confirm or disconfirm the hypothesis that anesthetized (or possibly comatose) patients are conscious (p.243)." As I have argued in the case of Tononi, there are legitimate reasons to suspect that a detector of consciousness will not be reliable enough to solve problems like the inverse zombie, nor is there any reason to think that one detector would be able to accurately measure the level of consciousness across species, as LaRock states as a prerequisite for such a machine (p. 243). Nonetheless, these concerns in no way suggest that functionalism itself is flawed, or that a form of emergent consciousness as property dualism must be accepted to explain these phenomena.

implies a graded scale of consciousness²⁶. Therefore choosing a place on the scale to represent sufficient unconsciousness is still likely to be arbitrary. Is there a reason to believe that such a measurement would be stable enough for a broad enough portion of the population to be valid, or would it vary according to different sub-divisions²⁷ (age, gender, ethnicity), and what would be the ethical and practical ramifications of this linear measure if it did? If such a meter must operate with values corresponding to the LOC possessing a high standard deviation, it again challenges the utility of such a measure, above and beyond other technologies. From the insight about the moment of transition for a percept from the moment of discrimination to the moment of reinterpretation in memory that can be gleaned from Dennett, it is easy to suggest that any meter than does not acknowledge the deeply arbitrary nature of its scale must be suspect.

Furthermore, even if Φ does track precisely with consciousness, will it also track with awareness²⁸? How will it correlate with both AWO and AWR? Awareness with explicit recall (AWR) is uncontestably undesirable, but the nature and ethical consequences of AWO are still up for debate (Garcia, 2010, p. 132). In these cases, the patient may still experience psychological fallout; it has been reported in pediatric populations that inadequate pain management can lead to “morphological change in the spine, and persisting changes in behavior, and poorer clinical outcomes (Davidson, 2010, p. 183).” Thus, cases of AWO should not be dismissed out of hand. As Garcia et al. (2010)note, the nuances of AWO versus AWR hinge on the difference between two types of memory: explicit and implicit (p.132). The

²⁶ Koch(2009) notes in his Scientific American article, that this implies that IIT is a form of panpsychism (p. 19).

²⁷ Split-brain patients: in his provisional manifesto, Tononi has characterized split-brain patients as possessing “two-consciousnesses.”

²⁸ The philosopher J.J.C. Smart (2004) distinguished consciousness and awareness by suggesting that consciousness is awareness *about* awareness (p. 43).

outcomes of AWO seen in pediatric patients are due to the ability to form implicit memories of painful stimuli (Davidson, 2010, p. 183). This is also borne out by the work of Merikle et al. (2001) who showed that perception and awareness are different phenomena, that perception without awareness does occur, and furthermore, that objects perceived without awareness modify the future perception of other objects (Merikle, 2001, p. 132). So how would IIT handle the differentiation between types of awareness, and how would Tononi's consciousness meter aid in the reduction of the psychological consequences attendant with implicit awareness?

Turning for a moment away from Tononi, similar questions must be asked of Dennett: namely, how does his model make sense of the information from the study of anesthetics? For MDM, as stated earlier, the moment of awareness is arbitrary. Furthermore, the purpose of perception is not to create a conscious experience, but to create concepts that can be used for future behavioral modification but the collection of abstract memories, associations, and drives that roughly constitute 'the self.' So, awareness, and attention, for this model do not result from the systematic binding of all of the separate streams of information processing for a final presentation in a version of the Cartesian theater, but the successive promotion of the narrative fragments that constitute individual discriminations, that only feel like a narrative, unified stream of consciousness (Dennett, 1991, p. 254). As he states, "Probing this stream at different places and times produces different effects, precipitates different narratives from the subject (Dennett, 1991, p. 113)." Probe too late and the percept will never reach awareness. Still, this doesn't definitely address the neuroanatomical knowledge that we have concerning what is happening in a literal sense in the brain when we 'probe' too early, or what is happening in a literal sense when the actions of "particular specialist areas" are enhanced by

the reticular formation in the midbrain in one possible description of attention that he offers (Dennett, 1991, p. 274). From a certain perspective, this is the great weakness of MDM, in that it spends a good deal of time deconstructing the illusions and mistakes of the past (the Cartesian theater, the central meander), but does not spell out what the virtual machine would actually need to contain. This is intentional: given the current state of knowledge about the neural correlates of consciousness (it was 1991 after all), the point of his project wasn't to find a single theory that fit with a list of conscious phenomena and , but to equip the scientists and philosophers with the proper conceptual language, to recognize that "we are still at the metaphor and hand-waving stage, but that is not a stage to shun; it is a stage to pass through on our way to more explicit models (Dennett, 1991, p. 274)." After all, it isn't enough that we swap old theories of consciousness out for new as our biological knowledge grows, we have to recognize the very real ways that our definitions of abstract concepts in the philosophy of consciousness shape how and what we study through the physical sciences. Conversely, we must also recognize that the methods that we employ (whether they are thought experiments, EEG studies, genomics, or behavioral studies) shape our definitions of abstract concepts²⁹. Thus, he states:

Similarly, the frontal lobes of the cortex, the part of the brain most conspicuously enlarged in *Homo sapiens*, are known to be involved in long-term control, and the scheduling and sequencing of behavior. Damage to various regions in the frontal lobes typically produces such opposing symptoms as distractibility versus overfocused inability to get out of ruts, and impulsivity or the inability to follow courses of action that require

²⁹ The arguments concerning the possibility of perception without awareness are a good example of this.

delayed gratification. So it is tempting to install the Boss in the frontal lobes, and several models make moves in this direction (Dennett, 1991, p. 274).

Still, from a pragmatic perspective, we are left in much the same place as we started, with no clear path towards reducing the number of instances of intraoperative awareness.

Just as Dennett is not concerned with what is happening when anesthetics induce unconsciousness, neither model addresses what is happening during development. As part of his justification for a materialist, functionalist view of the mind, Dennett does offer a chapter devoted to the evolution of consciousness, and there are a number of clues here as to how Dennett would handle such a question.

Tononi, for his part, is silent about child development, and the dramatic neural pruning of connections that occurs during it (Feinberg, 2010, p. 56). In their study, Feinberg et al. have tracked gross changes in EEG signal correlated with NREM sleep during adolescence, and found that these EEG changes with correlated with the culling of neural connections (p. 63-64). One important insight from their study was that this pruning and the corollary cognitive maturation was linked to age, and not relative position in puberty (p. 56). Instead, they suggest that these changes are genetically controlled (p. 64). They note that the number of connections in the brain peaks at around the age of five and then drops off until the age of twenty where it stabilizes throughout adulthood and early old age (p. 59). This suggests some interesting questions for IIT: first, they suggest that the “profusion of neuronal connections could make it difficult to distinguish and organize functionally the particular (and lengthy) neuronal chains that must underlie sustained logical operations and complex problem-solving (p. 60).” Feinberg et al. note that “it must underlie the immense capabilities of young children to acquire

information and complex motor skills” but also that “the cognitive abilities of 10-year-olds are unquestionably substantial. But they pale in comparison to those of 20-year-olds (p. 59-60).” This is self-evident. But the question for IIT is how would the comparison of Φ be between those two groups? Would it differ? The easy answer would of course be that Φ would be greater for the 20-year-old, because they are capable of much more complex thinking, but that might suggest that Φ was actually a measure of intelligence, or ability instead of consciousness. By most definitions, the consciousness that a 10-year-old is capable of fits the description of full consciousness. But does this make sense in the context of the massive reordering of neural connections that is occurring at that age?

Certainly, interesting things are occurring in the brains of very young children, and of those things is language. Hermer-Vasquez et al. demonstrated the importance of language in shaping human cognition with their dual-task study. Their study tested subject’s ability to alternately use geometric and nongeometric information to find an object after disorientation, and found that “humans’ flexible spatial memory depends on the ability to combine diverse information sources rapidly into unitary representations and that this ability, in turn, depends on natural language (Hermer-Vasquez 3-4).” A version has of this study in adults was done in children, and they found that in comparison with trials performed with rats, young children has approximately the same rate of success, whereas older children (>6), those who were able to produce “expressions conjoining spatial sense information with object color information (e.g., ‘put it [green ball] left of the orange one.’)” were able to navigate these tasks faster and more accurately than both rats and younger children (Hermer-Vasquez, 1999, p. 8).

Dennett's model is frank about the importance of language. In fact, the power that natural language has to shape thought—the vocabulary, grammar and semantics—is intricately tied to his description of the self: opaque, multiple, and not ideally rational (1991, p. 301). However, that language *shapes* thought is not the same thing as saying that language *is* thought, and MDM makes that distinction (p. 302). For MDM, natural language is an organizing principle for thought, a way to “constrain the brain in the manner of a high-level programming language (p. 302).” Much of the thinking we do when we are solving problems isn't in the form of the careful, conscious construction of sentences. We aren't consciously transforming or linking the brain states that correspond to concepts from one to another, and then assembling this new representation carefully in language. That has already been done ‘for us’ when we have thoughts in natural language, and this process of thought is closely related to our language use with others (p. 197). Thus, the form of inner dialogue we are familiar with, and think of when we imagine ourselves thinking, is a kind of silent auto-stimulation that pushes “some information through one's own ears and auditory system” as a “way of building a ‘virtual wire’ between the relevant subsystems (p. 196).” Of course, the ‘Great Encephalization’ that dramatically increased our brain size occurred before the development of language, and “innate specializations for language³⁰, hypothesized by the linguist Noam Chomsky and others, and now beginning to be confirmed in details of neuroanatomy, are a *very* recent add-on (p. 190).” But much of our representational plasticity comes out of our ability to use language—written, spoken, heard—to construct both concrete and abstract concepts and conjoin them (p.

³⁰ See: Zuidema, W., Verhagen, A. (2010) “What Are the Unique Design Features of Language? Formal Tools for Comparative Claims.” *Adaptive Behavior*. 18(1) pp. 48-65, and Hawkins, R. (2001) “The theoretical significance of Universal Grammar in second language acquisition.” *Second Language Research*. 17(4) pp. 345-367
And for the conceptual debate between nativists and constructivists, see: Akhtar, N. (2004) “Nativist versus constructivist goals in studying child language.” *Journal of Child Language*. 31(2), pp. 459-462

192). Much of it also comes from our ability to share these concepts, to replicate and transmit them as memes³¹. Human consciousness put another way, is:

...itself a huge complex of memes (or more exactly, meme-effects in brains) that can best be understood as the operation of a 'von Neumannesque' virtual machine implemented by parallel architecture of a brain that was not designed for any such activities. The powers of this virtual machine vastly enhance the underlying powers of the organic hardware on which it runs (p. 210).

Here, is the heart of Dennett's difference with Tononi—what IIT has postulated is a form of consciousness that is independent of the mechanism whose information it is measuring. The contributions that language, and culture, and social structure have on the phenomenology of human consciousness are ignored, and his theory seems to alternately be a theory of arousal or qualia, but not both. Returning for a moment to anesthetics, one of the most interesting insights from Purdon et al. (2013) in their study of the EEG signals during different stages of anesthetic depth was the importance of the saliency of a stimulus to the ability of an individual to respond under anesthesia (p. 5). Thus, the induction of unconsciousness during anesthesia isn't a holistic 'dimming' of consciousness and abilities, but fractional, and dependent upon the nature of the stimulus used as a measure. For IIT, is it enough to argue that a generalized disintegration of information is enough to explain this? Or do we need something more, recognition of the mechanisms themselves, or the nature of the systems and complexes that are being integrated? Within the schema of MDM, this takes the form of the 'software' of the 'virtual machine'. Michael Cerullo (2011) makes a similar critique, drawing upon an example

³¹ Memes, as defined by Dennett, are 'cultural units,' complex ideas that 'replicate themselves with reliability and fecundity (p. 201)."

from information theory: Shannon's theory of Kullback-Leibler-divergence is a theory of data communication, and as such, is not capable of dealing with semantics. Thus, when one gives the reply "no," the meaning of "no" is very different depending on whether it was in reply to "do you know what time it is?" or "will you marry me (p. 56)?" Tononi has written a paper with Edlund et al. (2011) that used computer simulated animats to compare the generated Φ of a system to that system's fitness. A very simple virtual agent, possessing six sensors, two actuators, and four internal nodes was designed, and run through an evolutionary program, where it was challenged to solve mazes, and allowed to replicate (Edlund, 2011, p. 5). They found through this simulation that the amount of Π generated within the animats correlated with their fitness (Edlund, 2011, p. 1). However, these animats are integrating sets of sensory information utilizing a system of memory and a system of prediction, but the sensory data that they are interpreting—though the mazes that they were asked to navigate were new—were not context dependent, in a true sense. These animates were responding much like the rats in Hermer-Vasquez et al.'s (1999) dual-task study; the rats were able to use geometric information about the space, such as the corner of the room versus a wall, to find objects reasonably well, but this performance was not improved by the additional of a non-spatial contextual clue (e.g., a strong odor), which full verbal human beings were able to do. By recognizing a scale of consciousness, it would be easy to account for the comparatively limited ability of the animats (or rats) compared with human beings as different grades of consciousness, but this doesn't seem to capture enough about how consciousness can manifest to make sense. If, at some time in the future, we are able to rigorously calculate Φ for neural systems-- humans, animals, animats—and give a numerical value to the level of consciousness of a finch, and of a human

under general sedation, would it not seem possible that certain grades of animal consciousness will have the same value for Φ as certain states of arousal in human beings? Does that tell us anything about the nature of consciousness?

Anthony Peressini (2013) has critiqued IIT, arguing that Π should not be thought of as a model of the quantity of consciousness generated, but only of qualia (p. 180). He cites several internal concerns, one of which relates to the calculation of the minimum information partition, or MIP. The MIP, as stated before, is the decomposition of the system into smaller units that leaves the least amount of information unaccounted for (Tononi, 2008, p. 220). As Peressini states, “In order for Φ to be well defined, it must be possible to show that the set of causally possible decompositions, D , has a minimal element relative to the value in question, in this case the ‘distance’ from $p(X_0(\text{mech}, X_1))$. Regardless of what is to be minimized (or maximized), the question of whether such a min/max exists and is unique over D is unclear (Peressini, 2013, p. 183-184).” Without proof of such a minimum, then a complex “has no definite Π , and if Π is consciousness, then the complex has no definite amount of consciousness (Peressini, 2013, p. 184).” Furthermore, he argues that the amount of Π , and therefore consciousness, generated by a system is also dependent upon the “particular (mechanistic) description one uses” and upon “the grain size” that must be varied in order to maximize Φ (Peressini, 2013, p. 184-185). These ‘internal concerns’ limit the value of IIT as a measure of consciousness, but do not foreclose the possibility of using IIT in the form of IITQ, an integrated information theory of qualia (Peressini, 2013, p. 204).

Ultimately, this is a problem too, because qualia are a problem. The problem with qualia is deeper than a disagreement about a philosophical term, or a phenomenological object, the

problem with qualia is that the acceptance of qualia assumes certain truths about our experience—that there are separate, non-reductionist truths about our experiences, even if cannot access those truths—that do not make sense within a materialist program. Accepting qualia, the truth in the way things feel to us, encourages us to validate the reports people give of their own experiences, to validate the causal explanations that subjects report about their experiences, and to perpetuate myths about the unity of our experiences and our possession of a rational, transparent self. Of course, this is obviously done through the arguments that are made against mind-brain identity, against materialism as a possibility, and against Physicalism in the philosophy of consciousness, but more subtly, this is done through the language and metaphors that we use to talk about functionalist, materialist models. This is why Dennett privileges his discussion of language, and places it at the center of his argument for an evolutionary, functionalist model of human consciousness, the anchor of his theory. It can be argued that the weakness of Dennett's model is that it doesn't offer a direct pathway to using mathematical, empirical methodologies to explore and quantify consciousness; however, his model does not foreclose the possibility of incorporating knowledge about the neural correlates of consciousness as it becomes available, or of creating artificial models of human intelligence or consciousness. The heart of his project is not to define the contents of our theories on consciousness, but to recognize the importance of theoretical memes as they are adopted and propagated through language in the discourses on consciousness, and create new memes that guide the discussion away from outmoded representations of human consciousness as a metaphysical substance, as a theater, or even just as the thing that is felt by a unified, atomistic self. Near the end of his text, Dennett describes his project as deconstructing one set of

metaphors for another (Dennett, 1991, p.455). But as he states, “but metaphors are not ‘just’ metaphors; metaphors are the tools of thought. No one can think about consciousness without them, so it is important to equip yourself with the best set of tools available (p. 455).”

In his own way, Tononi has provided his own metaphor for consciousness. However, by conceptualizing consciousness as Φ , he has limited the productive power of his metaphors to what is contained by the Kullback-Leibler divergence itself, which can be applied to different problems, but does not generate new meaning depending upon the context. In a general sense, this is why I have argued that IIT is not a productive way of thinking about consciousness—it is both poorly defined, in that the quantity of consciousness generated by a system is not definite, and too limiting, in that the manifestations of that consciousness are not entailed in the calculation of Φ despite real and meaningful differences in the consciousness experienced by adult humans, children, and other animals. Furthermore, I have agreed with Dennett that the concept of qualia is flawed, and suggested that Tononi’s incorporation of the concept into this theory of consciousness also poses a problem. I have argued that Dennett’s MDM is a more productive set of metaphors by which to think about consciousness, because of his recognition of the importance of language, social, and cultural factors (discusses here briefly as memes) despite his evasion of the neural correlates of consciousness. To do this, I have summarized key points about the models themselves, along with a short discussion of some context about consciousness. Then, I have reviewed the literature concerning anesthetics, and compared the two models of consciousness against what we have learned about the transition from consciousness to unconsciousness from their study. Finally, I have used the phenomenon of intraoperative awareness as a springboard to analyze some key concerns about IIT and MDM,

focusing on the different ways that each model quantifies consciousness as an indication of their conceptual framework.

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